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Improved Efficiency of Miscible C02 Floods and Enhanced Prospects for C02 Flooding Heterogeneous Reservoirs

Quarterly Report
July 1 - September 30, 1996

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Quarterly Technical Progress Report

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PRRC Report 96-30

Abstract

Progress has been made in each of the three project areas during this quarter. Each quarter we are highlighting one project area. This quarter, Task 3 is highlighted with expanded details.

Surfactant and foam properties have been evaluated at high pressure using the foam durability apparatus. For a number of surfactant solutions the interfacial tension (IFT) with dense CO_2, critical micelle concentrations, foaming ability, and foram stability were determined. Preliminary results show that these tests correlate well to predict surfactant properties and mobility in cores. Work has also restarted in the parallel-dual permeability system.

The agreement was good between tow simulators, MASTER (DOE's pseudo-miscible reservoir simulator) and UTCOMP (University of Texas Austin compositional simulator) in a test system with CO_2 foam. MASTER is presently being tested on a complex-real reservoir system. Also, we are examining improved methods to predict CO_2/oil phase behavior in near-critical regions.

CO_2/crude oil IFT measurements versus pressure and CO_2 gravity drainage experiments on whole cores at reservoir condition were completed during this past quarter. At 138ºF CO_2/crude oil IFTs dropped with increasing pressure until near the MMP above which there was little pressure effect on the IFT. Oil recovery from a 50 md Berea core in a 220 day test was 54% and increasing very slowly when terminated.

Executive Summary

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Introduction

Because of the importance of CO_2 flooding to future oil recovery potential in New Mexico and West Texas, the Petroleum Recovery Research Center (PRRC) has maintained a vigorous experimental program in this area of research for the past sixteen years.

New concepts are being investigated to improve the effectiveness of CO_2 flooding in heterogeneous reservoirs. Research is being conducted in three closely related areas: 1) further exploring the application of selective mobility reduction (SMR) in foam flooding, 2) exploring the possibility of higher economic viability of floods at reduced CO_2 injection pressures, and 3) understanding low interfacial tension (IFT) mechanisms with application to CO_2 flooding in tight vertically fractured reservoirs. Each of these areas have potential of increasing oil production and/or reducing cost in fields presently under CO_2 flooding. Also, the results of this research should expand viable candidates for future CO_2 flooding. Also, the results of this research should expand viable candidate fields to include lower pressure and much more heterogeneous or fractured reservoirs.

Results and Discussion

Summary of Progress

Progress was made in each of the three project areas during this quarter and is summarized in the next three paragraphs. Each quarter we highlight one project area. Thus, an expanded summary of Task 3 follows the summary paragraphs of the three tasks.

In Task 1 this quarter, surfactant and foam properties have been evaluated at high pressure using the foam-durability apparatus. The properties obtainable from these tests include the interfacial tension of the surfactant with dense CO_2, critical micelle concentration of the surfactant, foaming ability of the surfactant, and stability of the foam. These data were correlated with the dynamic properties of foam as measured from core flooding experiments. The preliminary results show that the stability of foam as derived from the foam durability tests can be used as an indicator to show the effectiveness of foam in reducing the mobility of CO_2 in the core flooding test. This is a better correlation than was found using surfactant properties and mobility reduction. Also, during the quarter we have restarted the system with dual permeability cores in capillary contact. We are running with and without foam, and with and without residual oil.

As part of Task 2, both MASTER (DOE's pseudo-miscible reservoir simulator) and UTCOMP (UT Austin's compositional reservoir simulator) were successfully modified to simulate foam flooding processes and tested using hypothetical cases. Agreement between MASTER and UTCOMP was good. Currently, MASTER is being run using the actual field data from the East Vacuum field to perform a history match with the field. A portion of East Vacuum has experienced water flooding, CO_2 flooding, and foam treatments. Our goal is to validate the foam model using this actual field data instead of a hypothetical case also we are presently examining methods to improve our predictions of CO_2/oil phase behavior in the near critical regions.

Progress has been made in Task 3 in two areas during the last quarter: 1) measurement of interfacial tension (IFT) of a CO_2/crude oil system under reservoir conditions, and 2) CO_2 gravity drainage experiment using a whole core and a crude oil under reservoir conditions. IFT of CO_2/crude oil was measured using our pendant drop measurement system. Experimental temperature is 138ºF. Pressure varies from 850 psig to 2200 psig. IFT decreases with increasing pressure until about 1600 psig where IFT stabilizes at about 2 mN/m. CO_2 gravity drainage has been conducted at the same temperature. Pressure varied during the 220 day test from 1700 psig to 2000 psig. Oil recovery from a 50md Berea core was 54% and was going up very slowly when the experiment was terminated.

Summary of Technical Progress
Task 3

Introduction

To understand the oil recovery mechanisms of miscible and near miscible CO_2 injection, we have measured the IFT of CO_2/crude oils in the near miscible region. The first oil sample measured was separator oil from Spraberry Trend Area of West Texas. The second oil sample was recombined Spraberry reservoir oil. The IFT of the CO_2/separator oil declines rapidly with increasing pressure until about 1,500 psig above which the IFT drops very slowly. The IFT of the CO_2/recombined reservoir oil also declines rapidly with increasing pressure until about 2,000 psig above which the IFT drops slowly.

To understand the principle of gravity drainage in fractured reservoirs, a gravity drainage experiment was conducted using a 50md Berea whole core and Spraberry separator oil in the presence of CO_2 at reservoir pressure and temperature. The color of the recovered oil varies from black to yellow. After 220 days, the experiment was terminated with a final oil recovery of 54%.

IFT Measurement of CO_2/Crude Oils

IFT of two CO_2/crude oil systems were measured versus pressure at 138ºF using the pendant drop apparatus in our laboratory. The oil used in the first system was Spraberry separator oil has been measured with a slim tube have a minimum miscibility pressure (MMP) of about 1,550 psig. The oil used in the second system was recombined Spraberry reservoir oil with and MMP of about 1,565 psig which is within experimental variation of the separator oil MMP. As required by the shape factor method[1] for IFT determination, phase densities of the two systems were also measured versus pressure. Presented in Fig. 1 are measured density data for the two systems. This figure demonstrates that the densities of the liquid and gaseous phases of the recombined oil are lower than that of the separator oil due to the presence of light components in the recombined reservoir oil. Shown in Fig. 2 are measured IFT data plotted against pressure. A composite plot of density difference against IFT is illustrated in Fig. 3 for the two systems.

CO_2 Gravity Drainage Studies

A CO_2 gravity drainage experiment was conducted using a 50md Berea whole core and Spraberry oil at reservoir pressure and temperature to investigate the effectiveness of CO_2 gravity drainage in fractured reservoirs. The experimental set up was described in the second annual report[2]. Experimental conditions are 138ºF and 1,700–2,000 psig. The color of the recovered oil varies from black to yellow. After 220 days, the experiment was terminated with an oil recovery of 54%. The oil recovery curve is presented in Fig. 4 on a semi-log scale. The measured IFT of the CO_2/separator oil has been used to simulate the gravity drainage using the mathematical model presented in the second annual report[2]. A good match between the experimental data and the model calculation is demonstrated in Fig. 4.

Discussion

It can be seen from Fig. 2 that the IFT of the CO_2 separator oil declines rapidly with pressure until about 1,550 psig which is similar to the MMP. At pressures above the 1,550 psig, the IFT drops slowly with increasing pressure (increasing mole fraction of CO_2). The CO_2/recombined oil has a similar trend with the IFT declining with pressure rapidly before 2,000 psig is reached. This was higher than the measured MMP of 1,565 psig. The discrepancy between the two systems regarding the relation between the MMP and the maximum miscibility IFT needs to be investigated in the future.

Although Fig. 1 and Fig. 2 demonstrate significant difference in IFT and density between the two systems, Fig. 3 clearly indicates that their IFT's have the same density-dependent behavior as they follow the same trend in the plot. However, as shown in Fig. 3, the slope deviates from the slope of 3.88 (defined by critical scaling) especially at high pressure (lower density differences). The 3.88 slope is defined by critical scaling law for pure substances, rather than for multicomponent compounds and Fig. 3 clearly shows the path dependence of critical scaling..

Conclusion

IFT of the first contact CO_2/crude oil systems decline rapidly with increasing pressure at low pressures. Near the MMP the decline in IFT slows and the IFT becomes less pressure dependent as the pressure is increased above the MMP.

A unique nonlinear decline curve of IFT with density difference exists for both CO_2/separator oil and CO_2/recombined oil. The slope of the curve is not constant on a log-log plot as opposed to a constant slope defined by critical scaling. This implies that use of the scaling for IFT of CO_2/crude oil may be erroneous.

Using the measured IFT for the CO_2/separator oil system, experimental oil recovery from CO_2 gravity drainage has been matched to a mathematical model with reasonable accuracy.

References

1. Fordham, S.: "On the Calculation of Surface Tension from Measurements of Pendant Drops," Proc. R. Soc., A194 (1948) 1

2. Grigg, R.B. and Schechter, D.S.: "Improved Efficiency of Miscible CO_2 Floods and Enhanced Prospects for CO_2 Flooding Heterogeneous Reservoirs," Annual Report for DOE Contract No. DE-FG22-94BC14977, 1996.

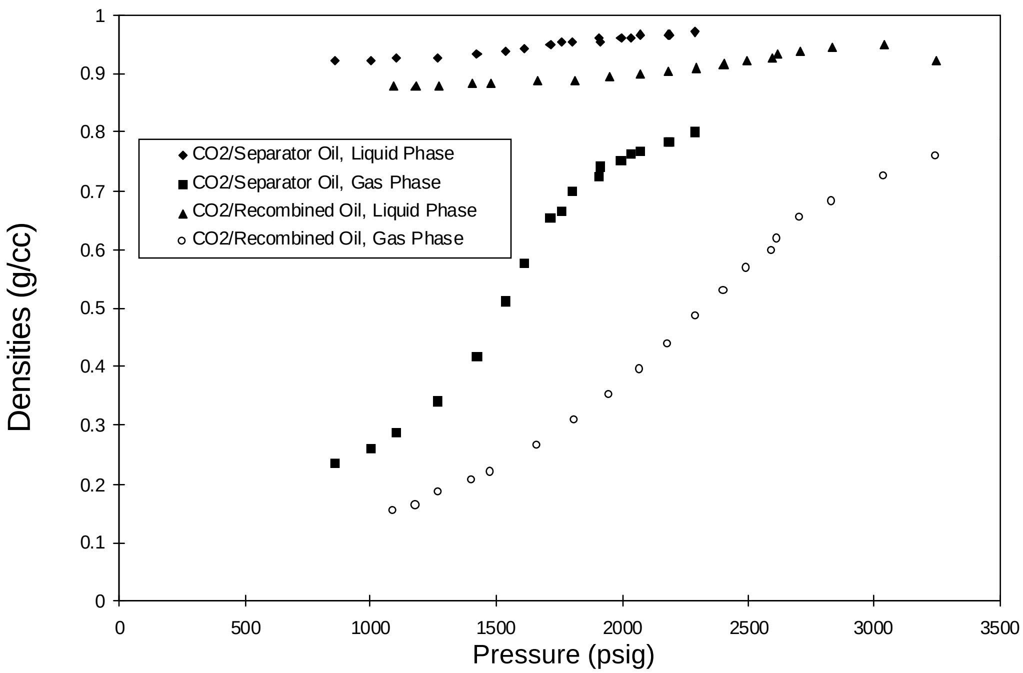

Figure 1: Measured Densities of CO_2/Oil Systems at 138ºF

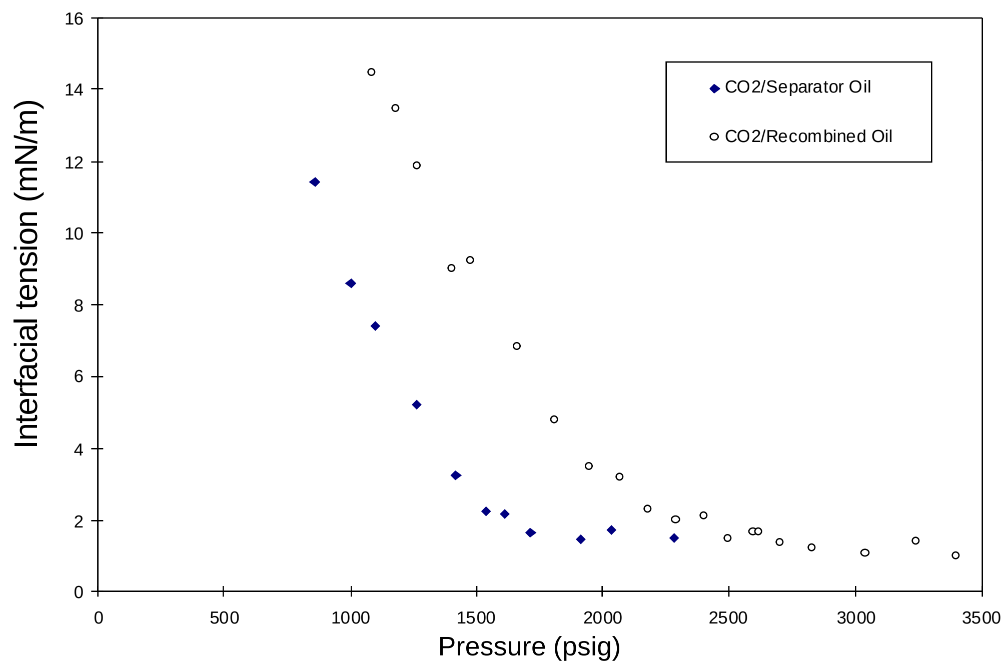

Figure 2: Effect of Pressure on IFT of Two CO_2/Oil Systems at 138ºF

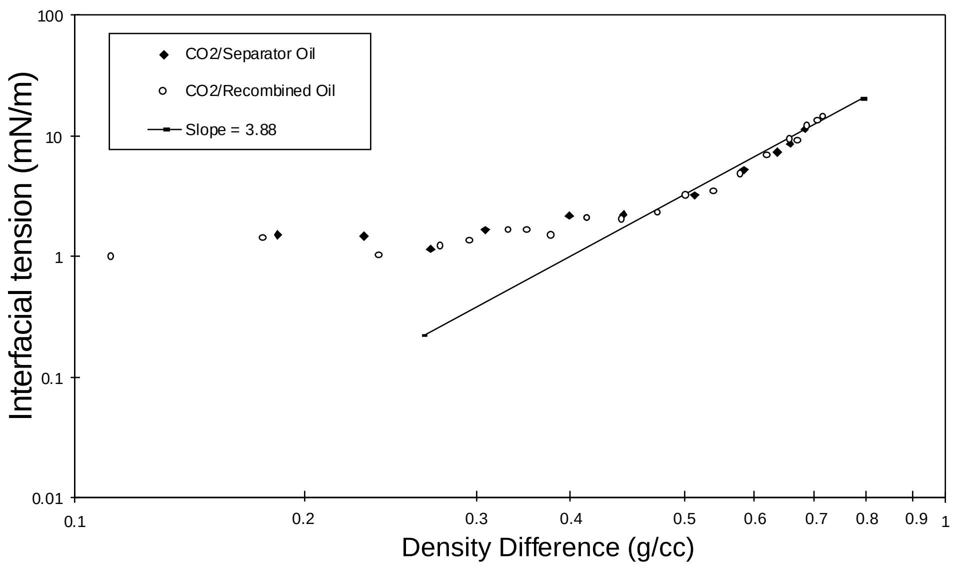

Figure 3: Relationship between Density Difference and IFT for Two CO_2/Crude Oil Systems at 138ºF

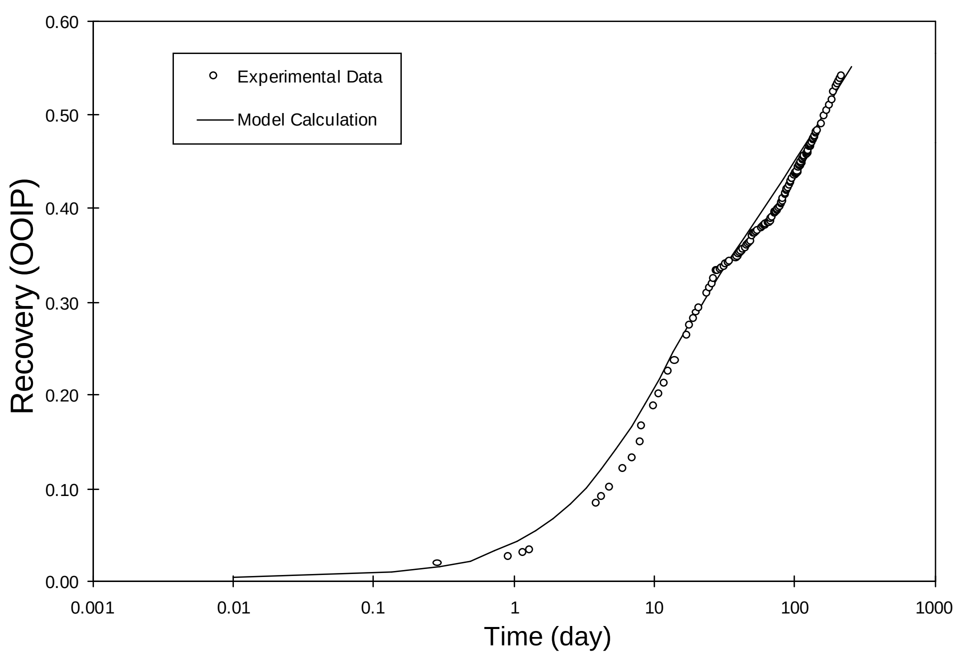

Figure 4: Oil Recovery during CO_2 Gravity Drainage from a 50md Berea Core